RHIC II High p_T Measurements and Bjorken **NON** Scaling

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Outline of Presentation

- Local Bjorken Scaling Violations
  - Rapidity “Triangle”, BGK model.
  - CGC Models?
- Local Scaling Violation Effects in A-A
  - RAA(φ,η,b)
  - Rotation and Dynamical Twists
  - Moments and Flow
- What do we need at RHIC II?
  - Some complications
  - High p_T, High luminosity, Identified Particles, High rapidity and full azimuthal acceptance

I. Nuclear Geometry and Bjorken Scaling Violations

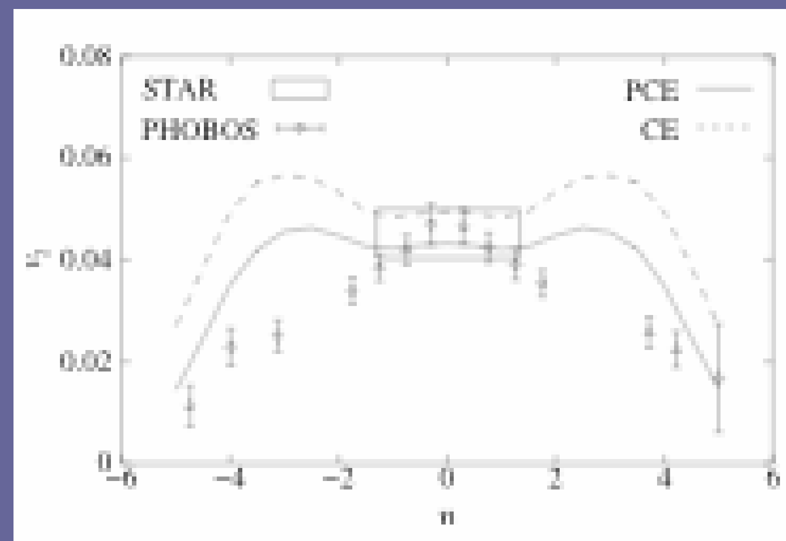
Bjorken Scaling

- Assume boost invariant rapidity structure of produced low p_T particle distributions in the initial state (mid rapidity plateau)
- Boost invariant initial distribution fed into hydrodynamic and flow calculations
- Good approximation for nucleus-nucleus collisions, only good to $O(A^{1/3}/\log(s))$

Bjorken **NON** Scaling at RHIC

- Bjorken Scaling only good when parameter $A^{1/3}/\log(s) = \delta \ll 1$
- At RHIC $\delta \sim 1$, even at LHC will be ~ 0.7
- Something not right in theory vs. data for v2 off mid rapidity
- Lets to look at whether any of this violation is from geometry

From hep-th/0410017



Details and future of hydro at RHIC

Tetsufumi Hirano right now in parallel

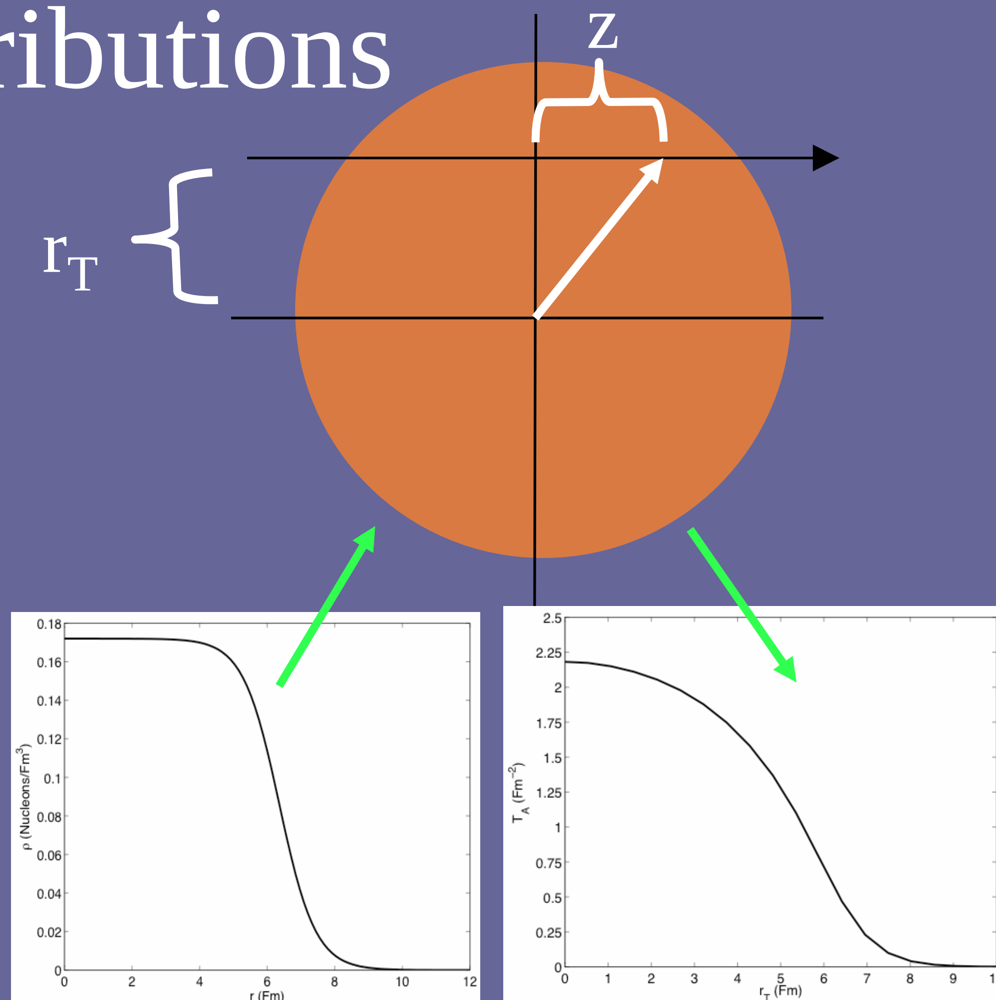
Single Nucleus Density Distributions

- Woods-Saxon Distribution

$$\rho(r) = \frac{a}{e^{\frac{r-R}{d}} + 1}$$

- Glauber Profile

$$T_A(r_T) = 2\int_0^{\infty} \rho(\sqrt{r_T^2 + z^2})dz$$



The p-A "Triangle"-BGK Model

- Low p_T particles are produced in η space as a "triangle"
  - Height $\propto \nu_A$

$$\nu_A(b) \approx \sigma_{in} T_A(b)$$

- Nucleon excitation at y_i
- Proj. color exc. $y_i < \eta < Y$
- Tar. color exc. $-Y < \eta < y_i$

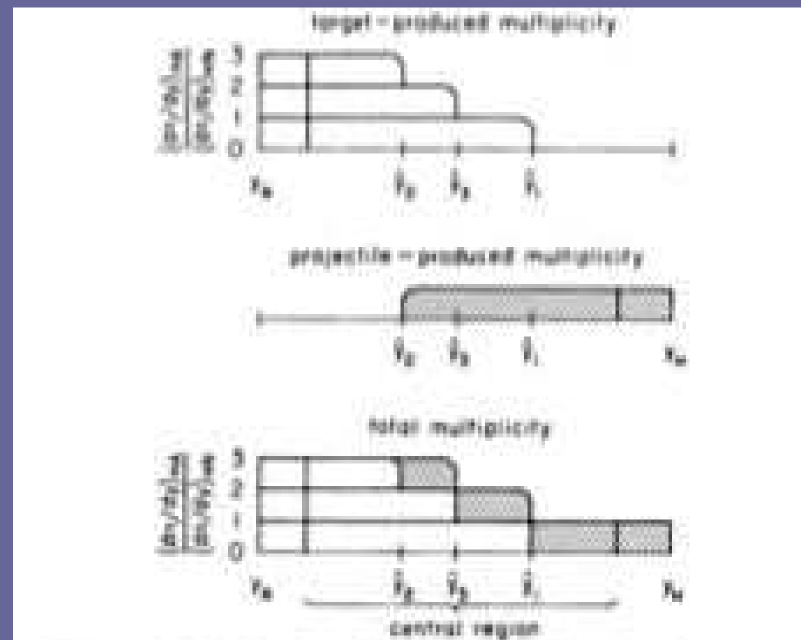
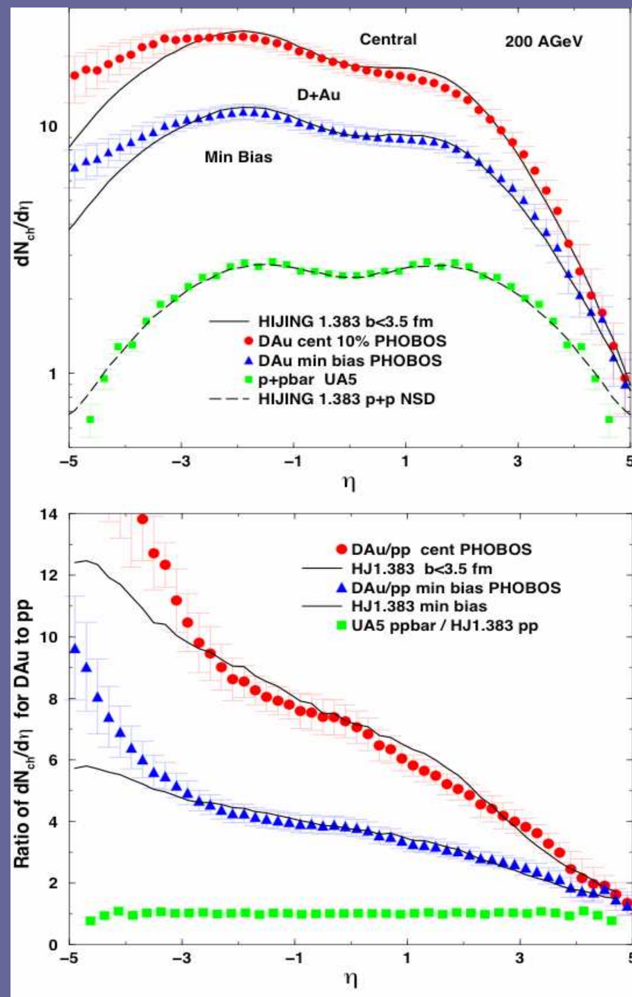


FIG. 1. Idealized multiplicity distribution for an N-A collision with $\nu = 3$ inelastic excitations. The y_i are uniformly distributed in rapidity and can be produced in any sequence.

Figure from Brodsky, Gunion, Kuhn 1977.

And It Exists!!!

- Monte Carlo event generators such as HIJING have QCD dynamics built in
- The multiplicity seen in the RHIC d-A experiment has just this “triangle/trapezoid”
- The shape is even more apparent if we look at it as a ratio



Implementation for A+B

INTRINSIC LOCAL BJORKEN SCALING VIOLATION O($A^{1/3}$/log(s))

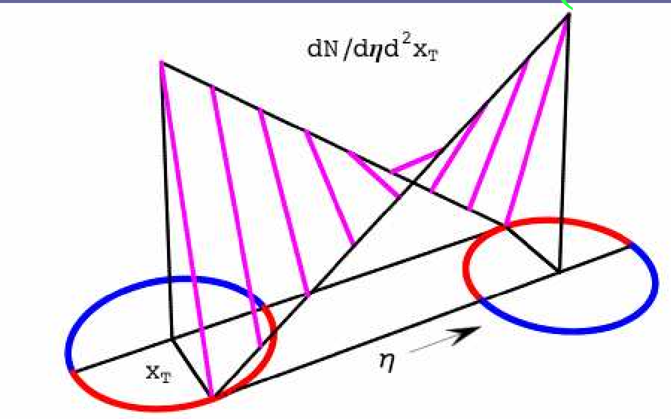
- Approximate local participant density with BGK

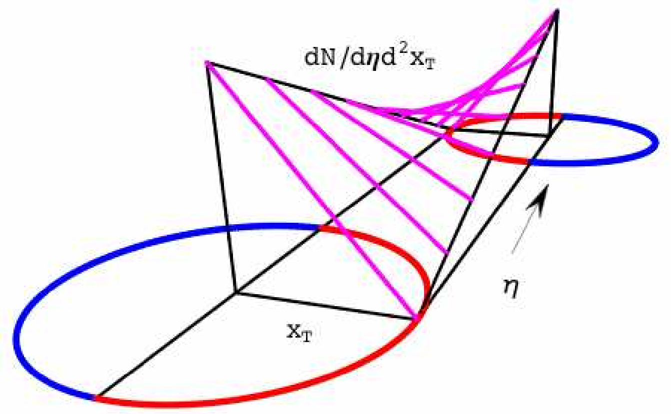
$$\approx \nu_A(\mathbf{x}_\perp - \mathbf{b}/2)\frac{Y-\eta}{2} + \nu_B(\mathbf{x}_\perp + \mathbf{b}/2)\frac{Y+\eta}{2}$$

- Can get global multiplicity

$$\approx \frac{1}{2}(N_A + N_B) + \frac{\eta}{2Y}(N_B - N_A)$$

- Note global multiplicity is boost invariant for A = B but not local density





What about CGC Initial State?

- The Color Glass Condensate (CGC) is QCD in the saturation limit and used to calculate multiplicities in nuclear collisions in the initial state
- Gives qualitatively similar results to the BGK model when calculating local participant density
- Also effects the jets and binary distribution, important for quenching calculations

Will come back to this later

II. Local Geometry and Dynamic Effects in A-A

Planar Participant and Binary Distributions

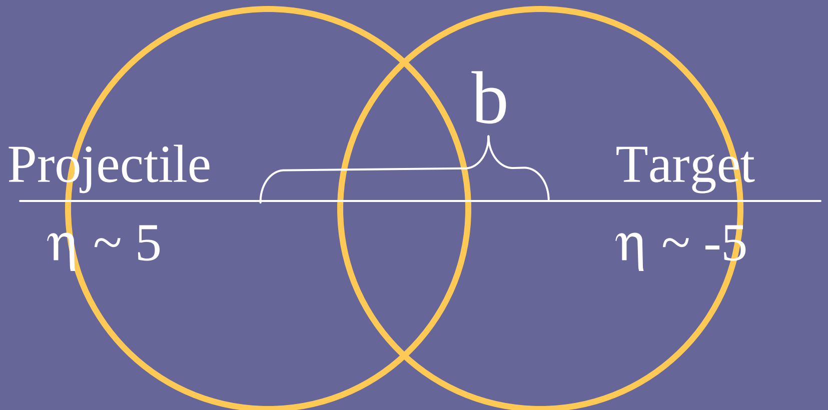
- Planar Distributions of all types

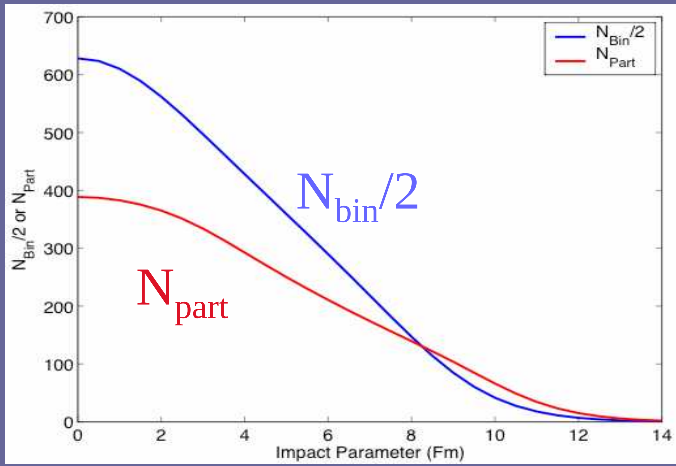
$$\frac{dN^{P/T}_{Part}}{dxdy} = T_A(r_\pm)(1 - e^{-\sigma T_A(r_\mp)})$$

$$\frac{dN_{Bin}}{dxdy} = \sigma T_A(r_+)T_A(r_-)$$

$$r_\pm = \sqrt{(x \pm \frac{b}{2})^2 + y^2}$$

- Total Participant and Binary Number calculated by integrating over transverse plane



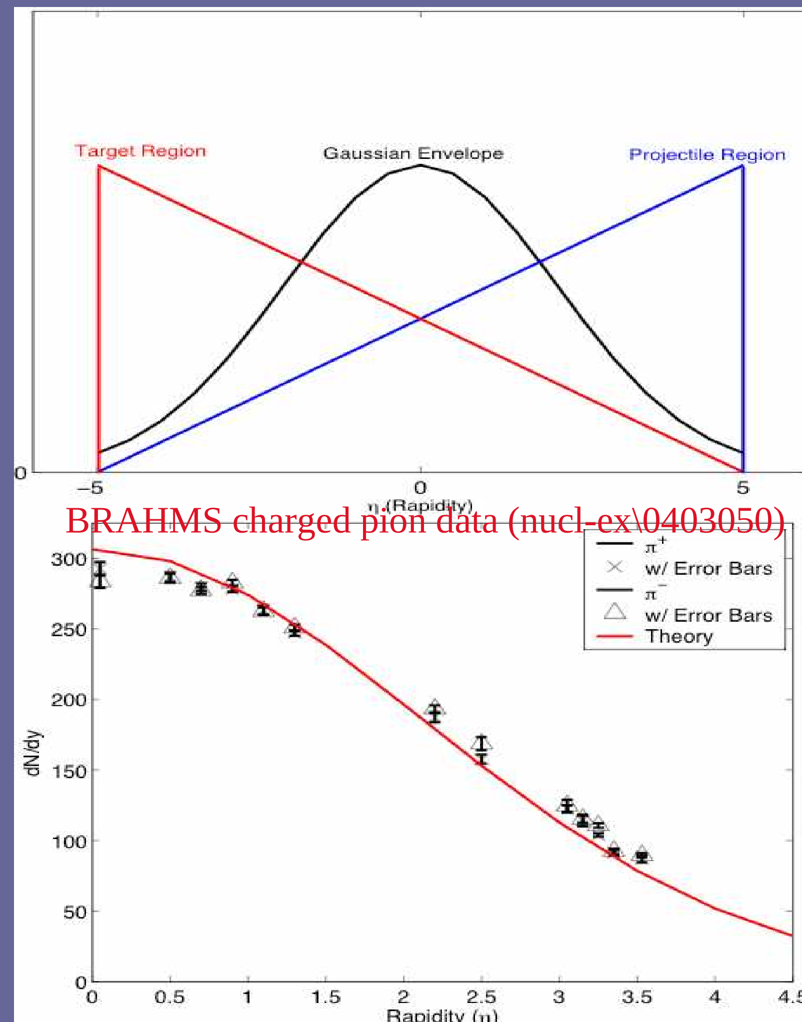


Adding Rapidity Dependence

- Distribution "inspired by" BGK model
- Exponential envelope inserted to model RHIC multiplicity

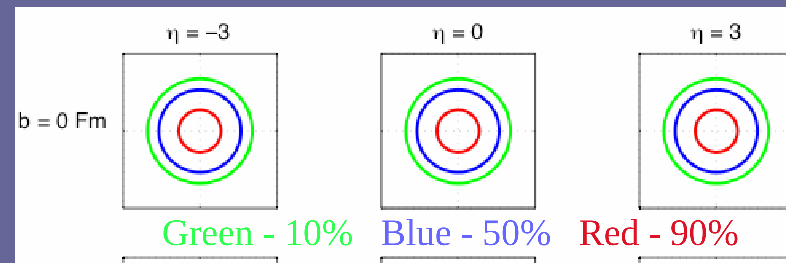
$$\frac{dN_{Part}}{dxdyd\eta} = \frac{C}{2Y} e^{\frac{-\eta^2}{\sigma_\eta^2}} \theta(Y - |\eta|) \left\{ \frac{dN^T_{Part}}{dxdy}(Y-\eta) + \frac{dN^P_{Part}}{dxdy}(Y+\eta) \right\}$$

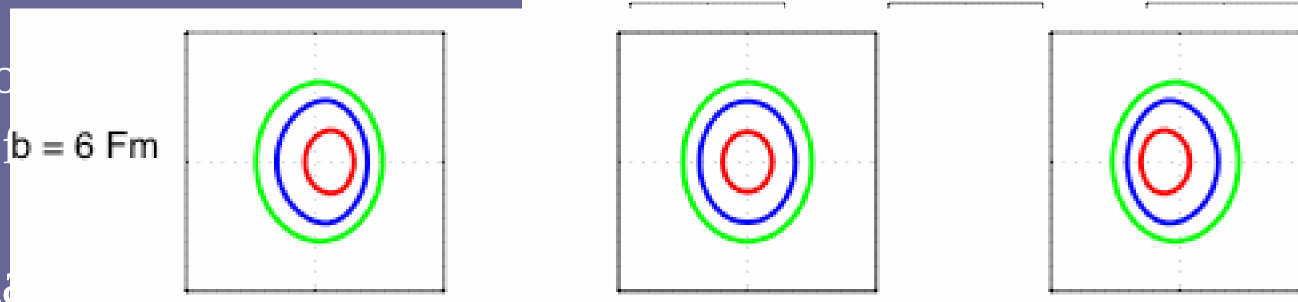
- Parameters set to RHIC central A-A
  - C ~ 1.6
  - Y ~ 5
  - σ_η ~ 3

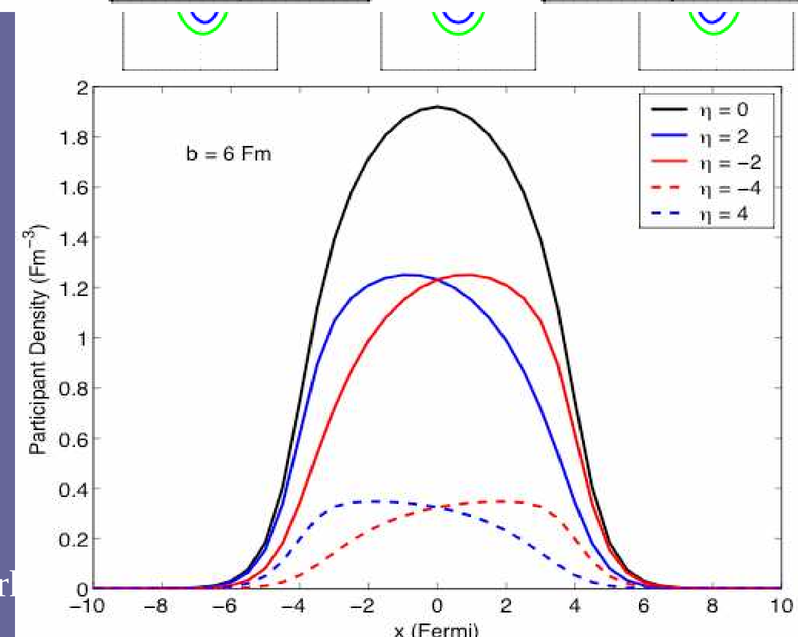


A Closer Look

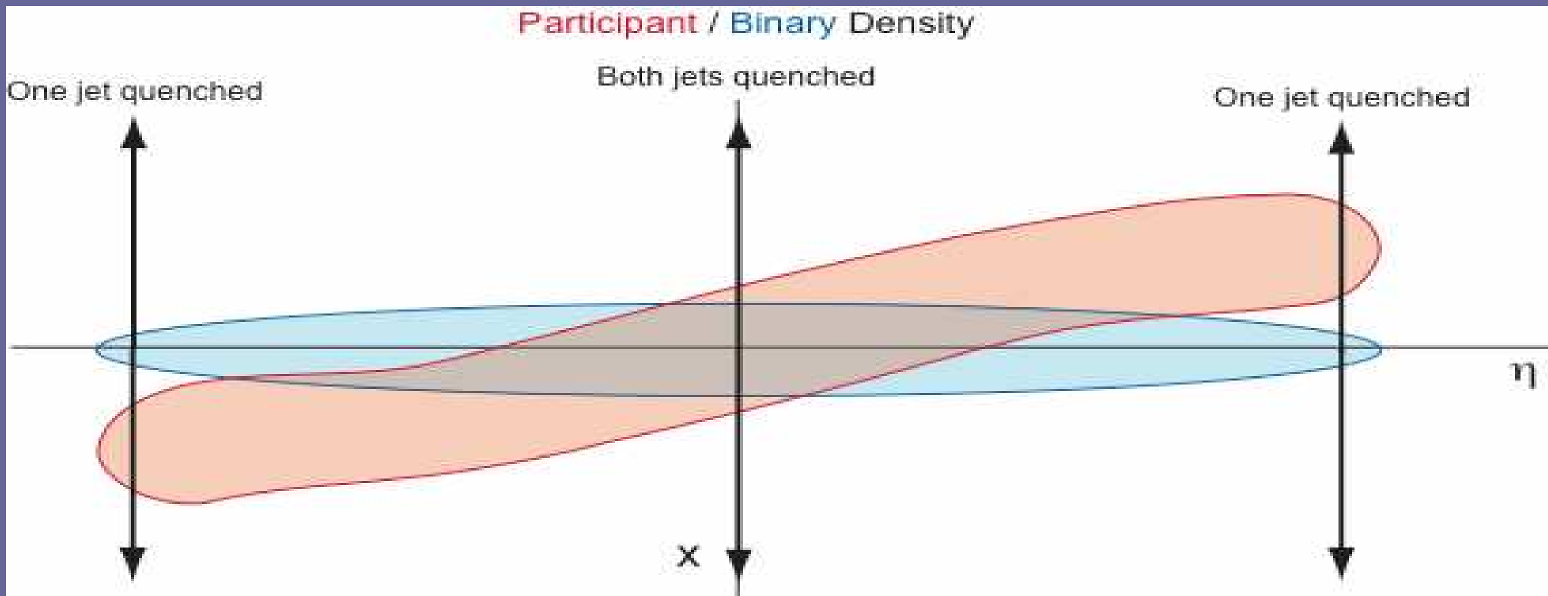
- Contour Plots show particular properties of the local density
  - Rotation aro
  - Zero effect parameter
- More quantita in second figure
  - Shift can be clearly seen
  - Drop due to overall exponential envelope is visible
- Similar geometries studied by Hirano/Nara







How to use Tomography



- Different rapidity regions effected by different initial nucleii (as seen from BGK model)
  - Asymmetry apparent in Participant density (rotation around y-axis)
  - Binary density unaffected (symmetric)
- Asymmetry can be probed via jet quenching
  - Long range rapidity anti correlations can be recorded.
  - Note : CGC complicates matters, stay tuned.

Opacity Line Integral

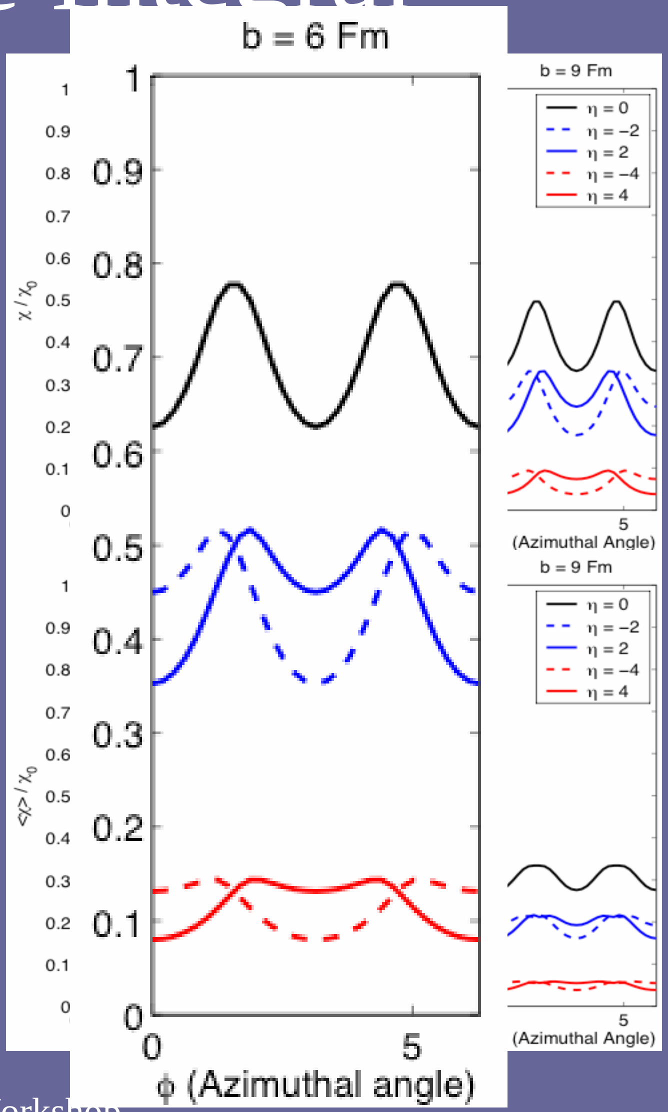
- Opacity defined as a line integral over local participant density

$$\chi_\alpha = \int_{\tau_0}^{\infty} \frac{dN_{Part}}{dx dy d\eta}(x_0 + t\cos(\phi), y_0 + t\sin(\phi), b) t^\alpha dt$$

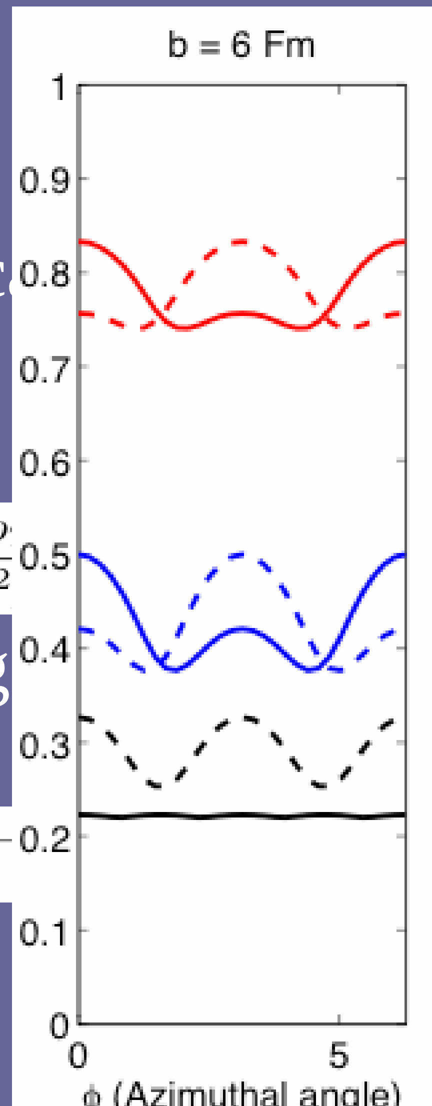
  - (x_0,y_0) origination point
  - $\alpha = -1,0,1$

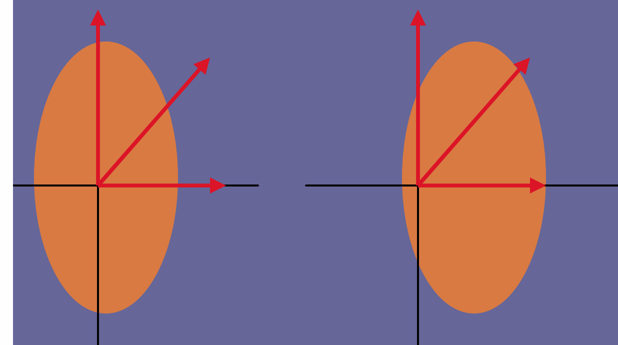
- We can average over geometrical fluctuations

$$\frac{1}{N_{Bin}} \int \frac{dN_{Bin}}{dx dy}(x_0, y_0, b) \chi_\alpha dx_0 dy_0$$



From … to R_{AA}





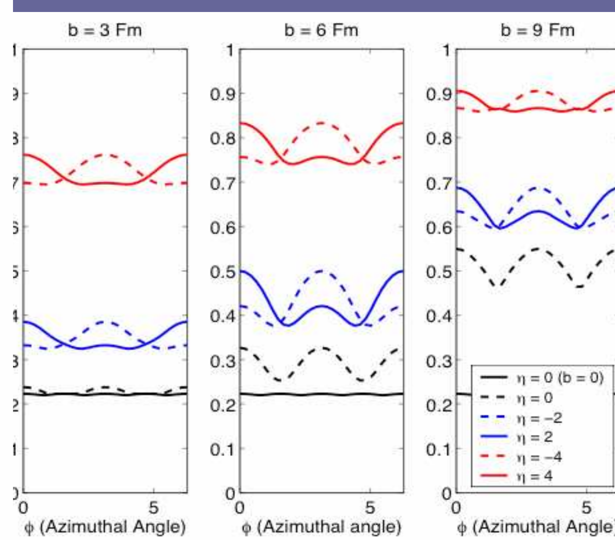
- Nuclear Modific… Factor is used to … nuclear effects

$$R_{AA} = \frac{dN_{AA}/d\eta d^2 p}{T_{AA}(d\sigma_{pp}/d\eta d^2}$$

- Calculated using … Drees, Jia et al.

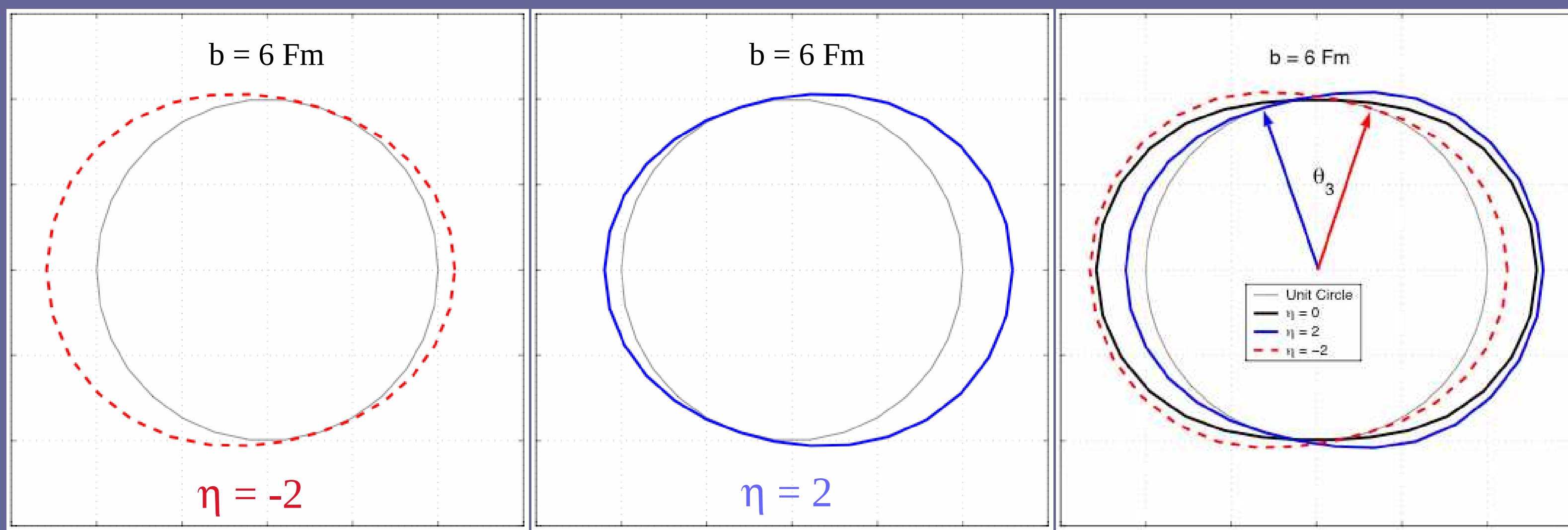
$$R_{AA} = \frac{1}{N_{Bin}} \int \frac{dN_{Bin}}{dxdy}(x_0, y_0, b) e^{-}$$

  - $\kappa \sim 0.25$



RAA from Another Perspective

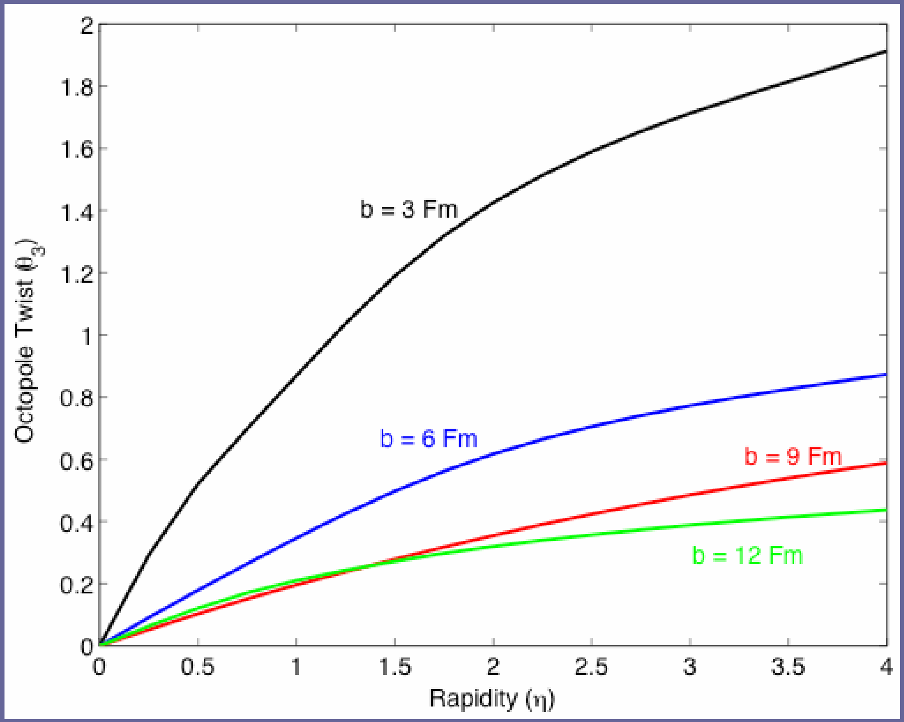
$$\frac{R_{AA}(\phi,\eta,b)}{R_{AA}^{min}(\eta,b)}$$



- Try to track asymmetry in Polar Plots
- Measure using Octupole Twist ‘θ_3’
- Long range anti-correlation over rapidity
- Dynamic effect due to long range anti-correlations in geometry

Octupole Twist Evolution

- Evolution with rapidity and impact parameter true prediction
- As one increases rapidity there is an increasing Octupole Twist
- Dynamic effect of a larger transverse displacement due to rotation around y-axis

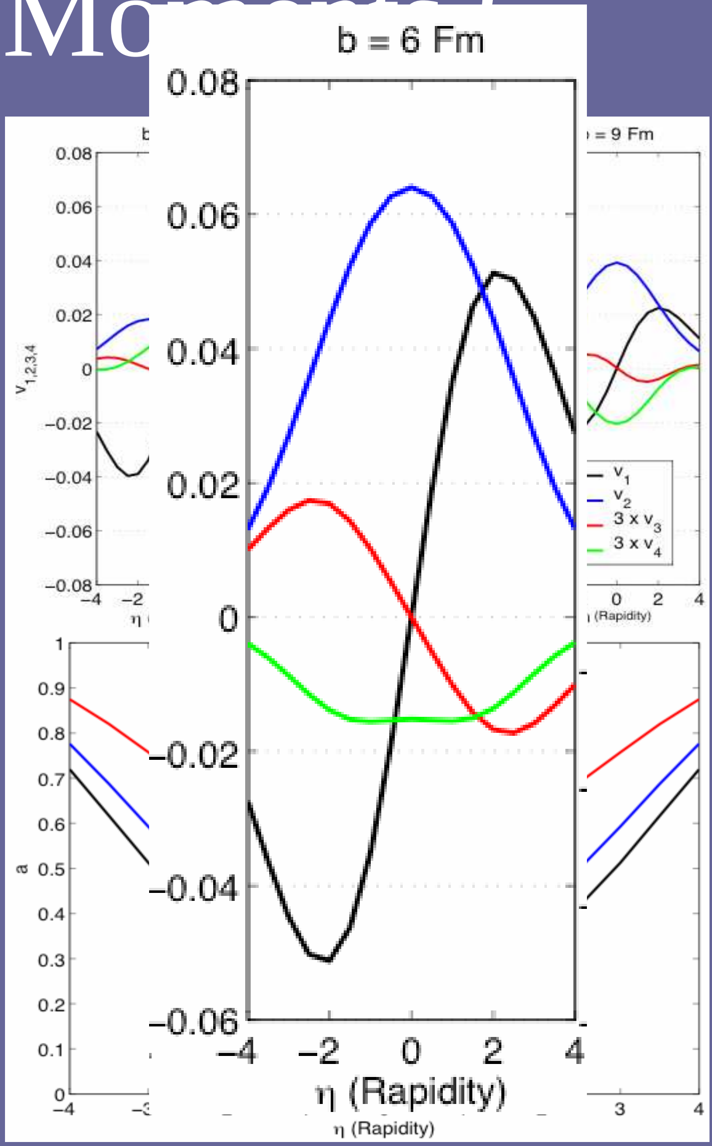


What about the Moments?

- Decompose R_{AA} into fourier moments

$$R_{AA}(\phi,\eta,b) = a(\eta,b)(1+2\sum_{n=1}^{4} v_n(\eta,b)\cos(n\phi))$$

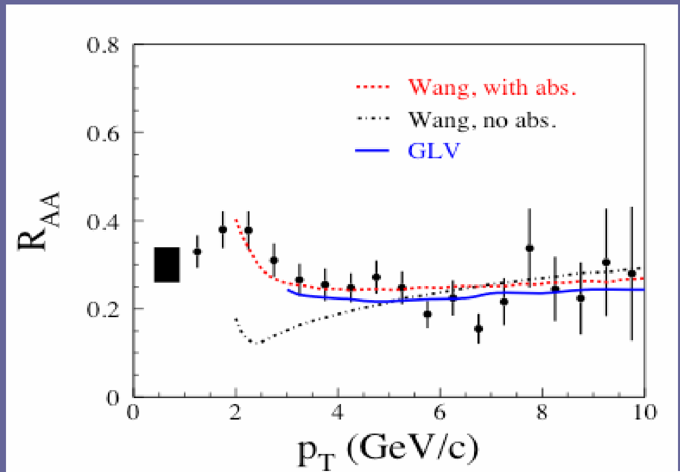
- Moments increase in magnitude with increasing asymmetry
- Higher moments increase in significance with larger b and η

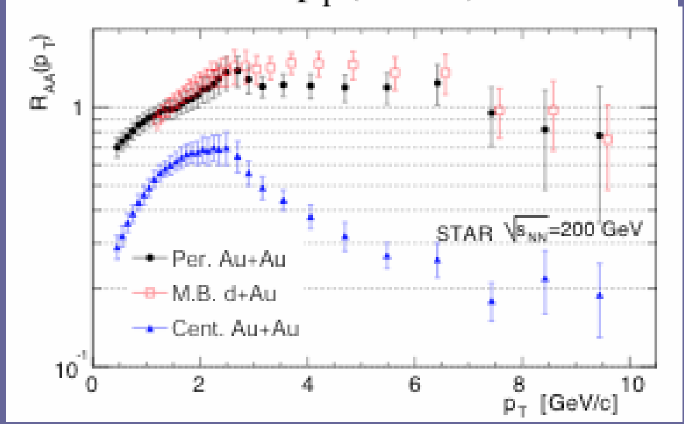


What do we need at RHIC II?

Particle Identification

From PHENIX nucl-ex/0410003



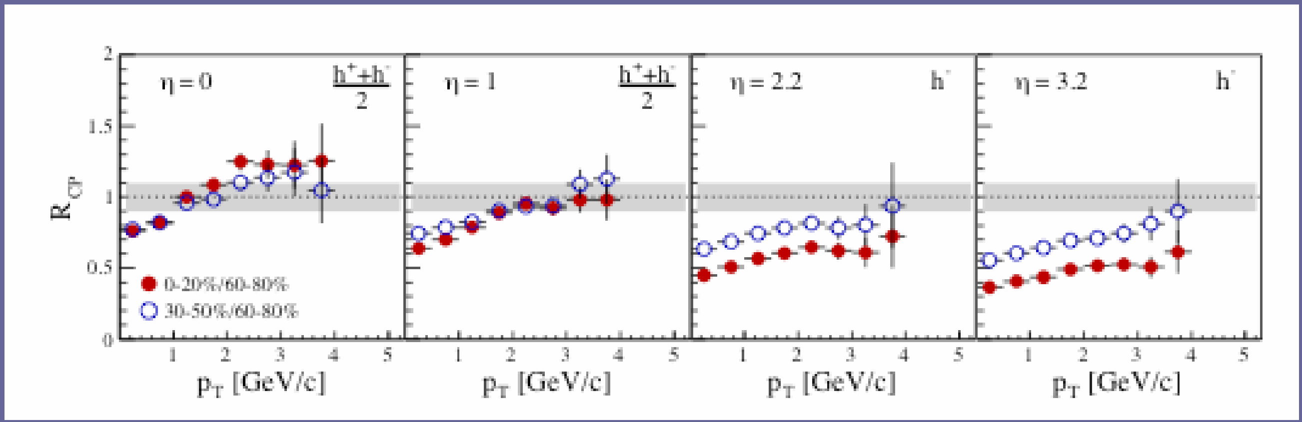


From Mike Miller's Thesis

- Tomography notoriously easier to perform using mesons (pions)
- Unidentified spectra include "baryon lump"
- To avoid this we need
  - Particle I.D.
  - Go to High p_T

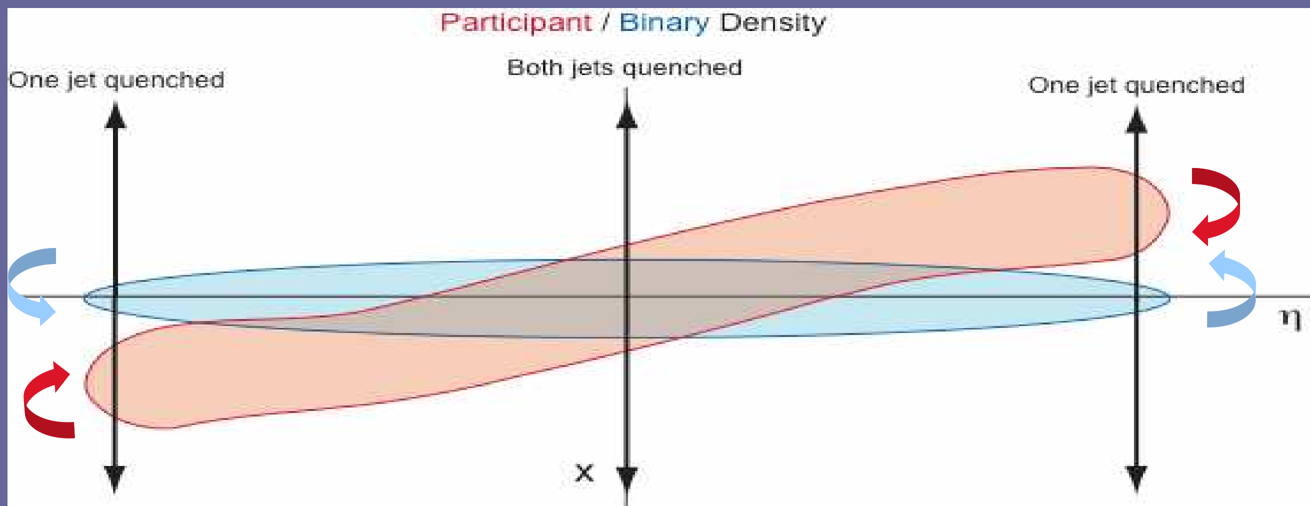
Complication d/t CGC/Shadow I

Figure from BRAHMS nucl-ex/0403005



- The d-A control experiment has provided some evidence for initial state quench off mid-rapidity
- In order to observe our effects one needs to be careful about accounting for this effect.
- Easiest solution, high enough p_T that it does not matter

Complication d/t CGC/Shadow II



- Shadowing functions tilt the Binary distribution

$$\frac{dN_{Bin}}{dxdy} = \sigma f_1(r_+)T_A(r_+)f_2(r_-)T_A(r_-)$$

- There are further tilts due to Cronin effects (X.N. Wang)
- Again, easiest solution is go to High p_T , still problematic though

In case you're still not convinced…

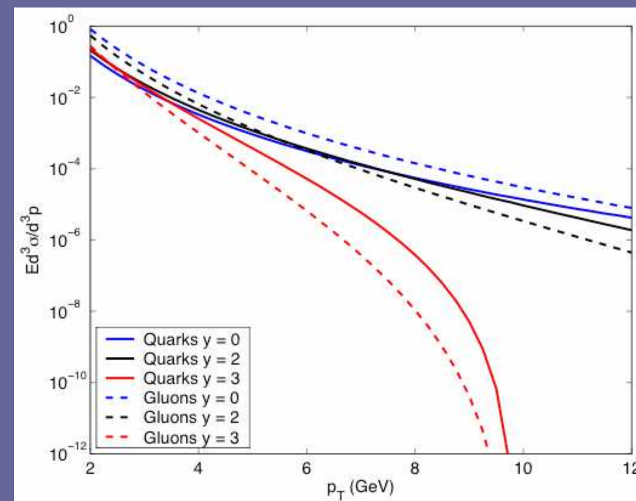
- All the quenching arguments used in previous sections are valid only at high $p_T \geq 5$ GeV
- All moments calculated are for jet like hard particles rather than soft bulk particles
- We NEED to be at high pT to find these interesting tomographic effects

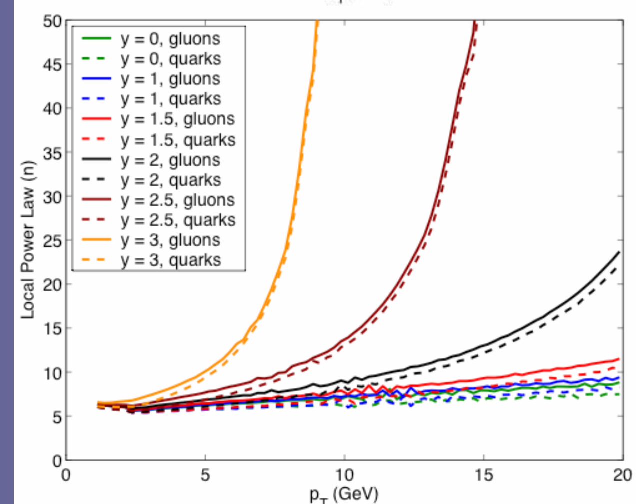
The Problem with High p_T

- We still need to consider underlying partonic spectra

$$\frac{d\sigma_{q/g}}{d\eta d^2 p_T} \propto \frac{1}{p_T^{n(p_T,\eta)}}$$

- "kinetic quench" needs to be considered
- Problem only gets worse with hadron spectra, $n_H \sim n_{g/q} + 2$





Finally, RHIC II

- After considering all our effects and complications we…
  - Need to detect identified particles (mesons)
  - Need to have broad coverage in η and φ
  - Need to cover out to large $p_T \geq 5$ GeV
  - Need High Luminosity in extreme areas

Conclusions

- Bjorken Scaling Violation is an important effect in A-A
  - A well known effect (BGK)
  - Has observable repercussions for tomography
- Including BGK effects leads to
  - Rotation of Participant Density
  - Induced Dynamic Twist Effect θ_3 in $R_{AA}(\varphi)$
  - Specific predicted fourier moments
- Further Complications from
  - CGC/Shadowing
  - Cronin
  - Need High p_T

WE NEED RHIC II !!!